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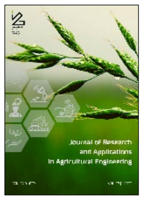

Laboratory Tests of Two Versions of a Planting Tool for Seedlings with a Covered Root System – Comparison, Part 1

Michał Szaroleta[a,b] * (https://orcid.org/0000-0002-1978-5755)
Stanisław Legutko[b] (https://orcid.org/0000-0001-8973-5035)
Dawid Kapela[a] (https://orcid.org/0000-0002-5054-8176)
Roman Rogacki[a] (https://orcid.org/0000-0002-2932-6763)
Jarosław Mac[a] (https://orcid.org/0000-0002-0888-9268)

[a] Łukasiewicz Research Network – Poznan Institute of Technology, Poznan, Poland
[a] Poznan University of Technology, Poznan, Poland

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This publication is aimed mainly at growers interested in improving the process of planting trees with a covered root system – in particular, in the use of a planting tool sunk into the ground. Two versions of the planting tool were made, with specific kinematics of operation. The tools differ geometrically, mainly in their diameter and the shape of the tip penetrating the ground. Tool penetration tests were carried out in laboratory conditions to assess their penetration efficiency. The research was conducted to determine how the tool's geometry affects the efficiency of its work. Another goal was to compare tools with two different shapes but the same work kinematics. As a result of the work, penetration values for both versions of the tool were obtained under the same working conditions, but these were laboratory conditions. The results obtained in theory indicate the greater efficiency of one version of the tool over the other. Practical conclusions also concern the aspect of tool strength, which is most likely lower in the case of the tool with more aggressive penetration characteristics. The key outcome of the research for those interested in implementing a tool for planting trees with a covered root system is that it indicates the advantages and disadvantages of both versions of the tool, including those relating to the efficiency of operation. The results require confirmation through research in real conditions (field conditions), where the variability of soil parameters is significant.

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1. Introduction

Manual work performed in forestry consumes considerable energy resources, while also often being burdensome and not ergonomic. For many years, research has been conducted in this area, while at the same time manufacturers, including both larger and smaller companies, have marketed solutions to improve the quality of work [4, 5, 10]. The range of products on offer is richer from year to year, while the designs of currently available devices for planting are very diverse in terms of the degree of complexity, production costs, and the possibility of supporting the operator's work. Therefore, there is

* Corresponding author: michal.szaroleta@pit.lukasiewicz.gov.pl

a need to work on improving the quality of equipment and tools. This will allow forestry work to be carried out more efficiently and reduce energy demand [1, 2, 7, 13, 19].

2. Purpose and scope of the study

The aim of the study was to compare two versions of a tool for planting trees with a covered root system. This tool was one of the components of the entire planting process. The first version of the planting tool was designed for use in a self-driving robot. This tool is used in the final stage of the planting process and is supported by systems such as a roller to prepare the planting site, a seedling magazine, a gripper with a buffer to feed the seedlings to the tool, and press wheels that complete the single seedling planting stage. During tests in real conditions, certain defects of the tool were observed, which reduced the quality of its work. In terms of the quality of the work of the first version of the tool, it is desirable to eliminate the jamming of the seedling in the inlet pipe and to improve the process of sinking the tool into the ground. The last parameter is the subject of the research described in this paper [10, 12, 15].

3. Subject of study

The subject of the research is a planting tool for tree seedlings with a covered root system, which was made in two versions. These versions differ in geometry, but have the same working kinematics. Fig. 1 shows a general view of the first version of the tool (right) and the second version (left). The tool features two symmetrically positioned arms, which are attached to the frame on pins. They are set in motion by the action of a hydraulic actuator. When the actuator closes, the arms rise and move away from each other [3, 6, 8, 16]. Table 1 gives the geometric differences between the two versions of the tool.

The main difference between the two versions of the tool is their shape. In the case of the first version (labeled V1) the recessed tip has a wedge shape. The countersink tip of the second version (labeled V2) is cone-shaped. Another important parameter that was changed in the second version of the tool is the cross-sectional area of the seedling guide tube. The V1 tool has a circular cross-section with a constant diameter of 60 mm. The V2 version of the tool has a cross-section similar to a truncated circle, and its diameter ranges from 66 to 80 mm, depending on the place of measurement. The increase in the cross-section of the tool is intended to facilitate the passage of seedlings and prevent them from getting stuck inside the tube [11, 14, 17].

Table 1. Requirements for specified mechanical properties for particleboards with a thickness range of 13 to 20 mm (EN 312:2010)

Characteristic	V1 tool	V2 tool
Inner diameter [mm]	60	66–80 (depending on the measurement point)
Outer diameter [mm]	70	86
Recessed tip shape	wedge	cone

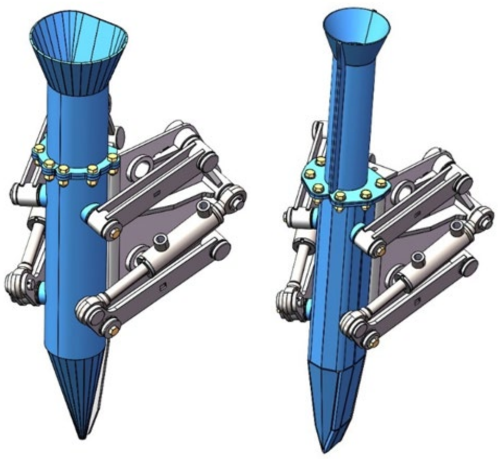

Fig. 1. General view of the model in the first version (right) and in the second version (left)

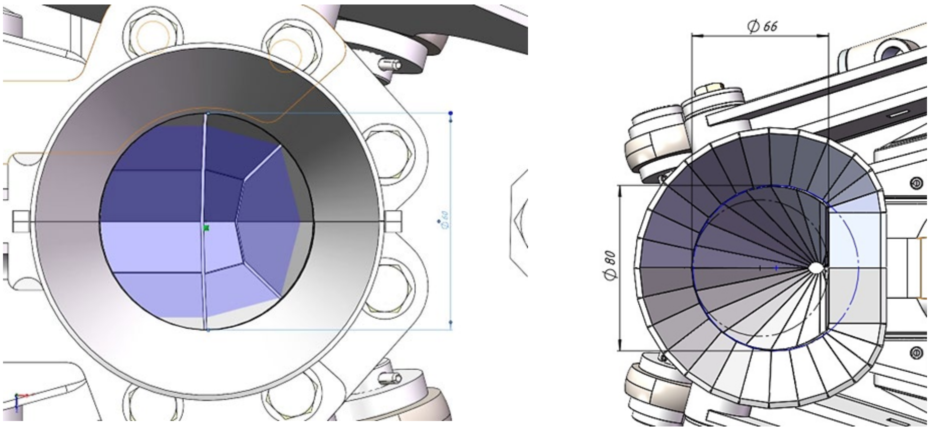

Fig. 2. Cross-sectional view of V1 tool (left) and V2 tool (right)

At the design stage, both versions of the tool underwent Finite Element Method analysis. In both cases, the requirements for the described structures were met. Tests in real conditions conducted using the V1 tool confirmed this.

4. Study methodology

The tools were tested in laboratory conditions. To reflect the soil conditions in which the tool operates, a metal container was filled with soil. The soil (light and dry following seasoning) was poured into the container manually with a shovel, and the container was shaken to make the density uniform throughout. Fig. 3 shows the functional model of both versions of the tool, and also the tool mounted on the frame [9, 17, 18].

The tank was a cylindrical barrel with an internal diameter of 385 mm and a height of 510 mm, which was filled with soil to a height of 385 mm. The soil poured into the container had a volume of 44.8 dm3 and a mass of 34.2 kg. Figure 4 shows the soil tank in which both versions of the tool were tested. The tests involved gradually sinking both versions of the tool into the tank filled with soil.

A DEE 5J37303 force sensor and an AXIS FB00 meter were used to perform measurements to compare the force needed to sink both versions of the tool. On one side, a pressure plate was attached to the force sensor, which was horizontally supported on the inlet flange of the planting device. On the other side of the sensor, there is an eye attached through which a rod is inserted that serves as a lever during digging. The force sensor was connected to a meter, which was used to indicate the value of the current insertion force of the tool. When a specific force value was reached, the tool's depth of penetration was measured. Care was taken to ensure that the inserted tool was positioned vertically. The vertical position was corrected during penetration using a spirit level. The photographs below show the tool embedded in the tank with soil together with the force measurement system (Fig. 5) and the measurement of the depth of the tool embedded in the tank with soil (Fig. 6).

Fig. 3. View of functional models of both versions of the tool, from left: second version (V2), first version (V1), V1 mounted on a frame

Fig. 4. Tank filled with soil into which the planting tool was inserted

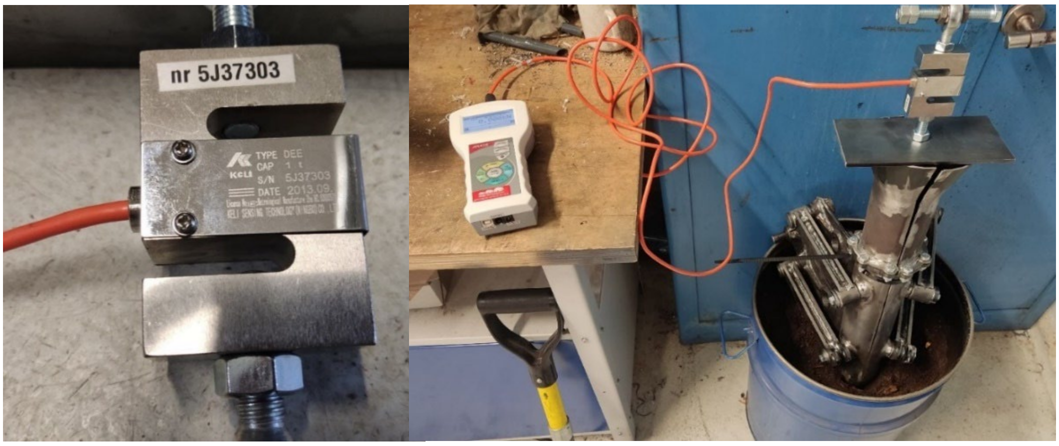

Fig. 5. Force sensor (left), test stand with tool inserted (right)

Fig. 6. Measurement of the depth of the tool in the tank after reaching the set force value

5. Results

The results collected during the tests are presented in Table 2. Column 1 gives the value of the force with which the tool was embedded when the tool depth was measured. Columns 2 and 4 present the counter-bore values in a given step for the V1 and V2 tool, respectively. The given values take into account the difference in height of the tools. The given value refers to the absolute change in height in a given digging step. Columns 3 and 5 contain the cumulative value of the recess starting from the first step. Three penetration tests were carried out on the V1 tool, and three on the V2 tool.

Table 2. Test results showing the indentation after each step and the total values depending on the applied force and statistical values

	Applied force [kN]	Recess in the given step [mm]	Total depth [mm]	Recess in the given step [mm]	Total depth [mm]
		V1		**V2**	
Attempt 1	0.00	0	0	0	0
	0.10	7	7	9	9
	0.15	7	14	11	20
	0.20	4	18	9	29
	0.25	9	27	11	40
	0.30	5	32	8	48
	0.35	10	42	7	55
	0.40	7	**49**	6	**61**
Attempt 2	0.00	0	0	0	0
	0.10	7	15	5	10
	0.15	9	24	11	21
	0.20	5	29	7	28
	0.25	4	33	9	37
	0.30	7	40	7	44
	0.35	4	44	6	50
	0.40	6	**50**	7	**57**
Attempt 3	0.00	0	0	0	0
	0.10	7	17	9	6
	0.15	7	24	6	12
	0.20	5	29	10	22
	0.25	5	34	9	31
	0.30	6	40	6	37
	0.35	5	45	9	46
	0.40	6	**51**	7	**53**
Mean value		6.29	-	8.05	-
Standard deviation		1.68	-	1.83	-
Variance		2.81	-	3.35	-
Confidence level		0.95			
Variable t		3.182			
Standard error		2.3824	-	3.0121	-
Critical value		9.0451	-	11.0571	-
Confidence interval		5.12–7.45	-	6.78–9.32	-

Analyzing the collected data, it can be seen that in almost every step, the second version of the tool, at a given force, penetrated deeper than the first version. The total depths achieved by the V1 tool with an applied force of 40 kN were 49, 50 and 51 mm in the first, second and third tests, respectively. For the V2 tool, the values were 61, 57 and 53 mm. From statistical analysis, it was concluded that the average tool penetration in a successive step at a given force is within the range 5.12–7.45 mm for tool V1 and 6.78–9.32 mm for tool V2, with a probability of 95%.

The values obtained are presented on graphs (Figs. 7–9) to visualize the tool penetration characteristics.

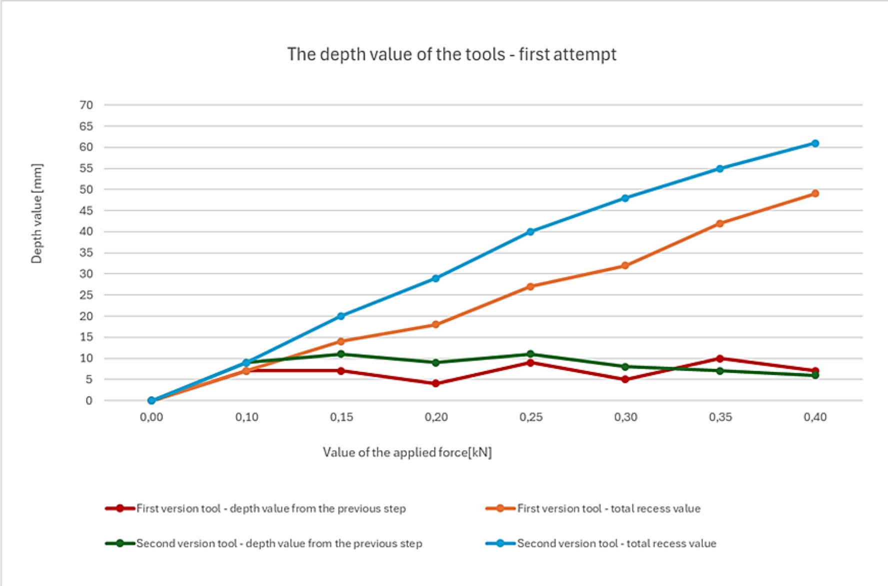

Fig. 7. Graph of tool penetration achieved with V1 and V2 (total penetration value and penetration value in individual steps) at the first attempt

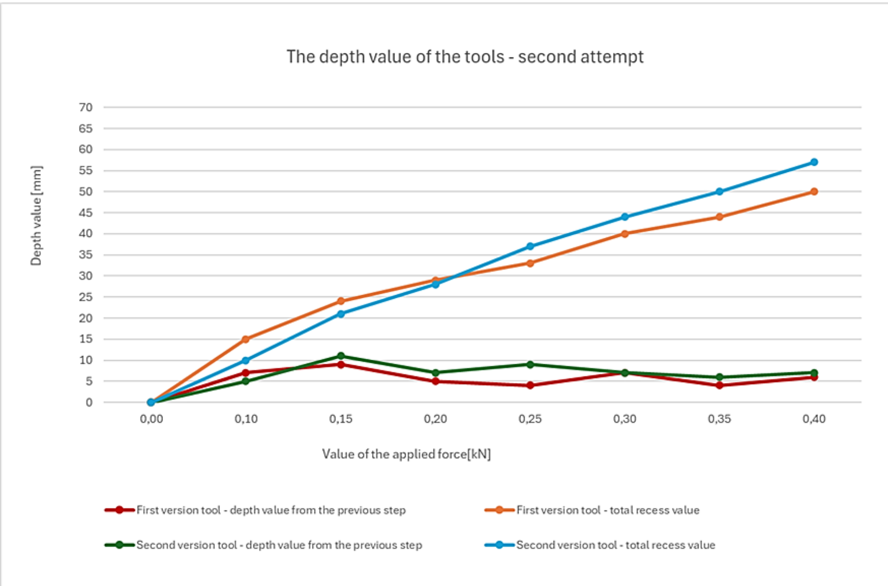

Fig. 8. Graph of tool penetration achieved with V1 and V2 (total penetration value and penetration value in individual steps) at the second attempt

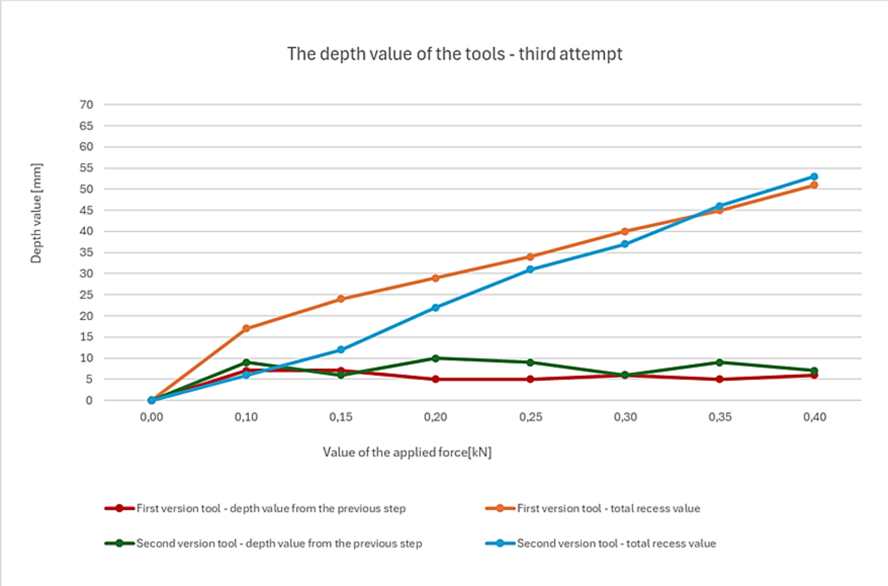

Fig. 9. Graph of tool penetration achieved with V1 and V2 (total penetration value and penetration value in individual steps) at the third attempt

6. Discussions

The tests allowed us to observe the slightly different penetration characteristics of both versions of the planting tool. A visible trend can be observed on the graph showing the total depth reached by the tool. In the entire test range, i.e. from the application of a force of 0.1 kN to 0.4 kN, the second version of the tool (V2) was more effective. The V1 tool reached a depth of 49 to 51 mm (depending on the penetration test) with a load of 0.4 kN. The V2 tool reached a depth of 53 to 61 mm with a similar load (also depending on the test).

It is important to note that both versions of the tool have advantages and disadvantages. The V2 tool, despite its geometry facilitating penetration, also tends to wear the conical tip faster due to the more aggressive nature of its work. The V1 tool is therefore characterized by greater durability against abrasive wear, but at the same time lower penetration efficiency. It is therefore worth considering the use of a harder material, more resistant to abrasive wear, e.g. Hardox 600 steel, at the manufacturing stage.

It should be remembered that soil can be described by many parameters (such as compactness, moisture, and chemical composition), which can affect the test results, although during the tests reported here these parameters were not measured, because the purpose of the tests was to compare the operation of the two versions of the tool under the same conditions. In order to make a comprehensive assessment of the quality of work of both versions of the tool, it would be reasonable to compare the quality of their work in real conditions. This would allow us to confirm or negate the results obtained in laboratory conditions. Such studies will be carried out in the near future as part of the continued work on improving the planting tool.

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